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Material Handling Equipment Evaluation for Crater Repair

W. Jeremy Robinson, Jeb S. Tingle, and Craig A. Rutland

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Abstract

Research was conducted at the U.S. Army Engineer Research and Development Center in Vicksburg, MS, to evaluate material handling equipment with a reduced logistical footprint for use by crater repair teams in airfield damage repair (ADR) scenarios. A market survey was conducted of available material handling equipment to populate a database of physical dimensions and load-capacity relationships according to identified ADR tasks. Selected equipment were identified and evaluated for maneuverability and efficiency in a realistic environment and compared to currently utilized material handling equipment. This report presents the results of the market survey and equipment evaluations. Results indicate that telehandlers with a minimum-rated capacity of 6,000 lb are capable of performing all identified ADR tasks with an efficiency at or better than the currently utilized 10,000-lb telehandler.

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Preface

This study was conducted for the U.S. Air Force Civil Engineer Modernization Program sponsored by Headquarters, U.S. Air Force Civil Engineer Center (AFCEC) located at Tyndall Air Force Base, FL. Dr. Craig Rutland, AFCEC, provided technical guidance and review during the project. Jeb. S. Tingle was the ERDC Airfield Damage Repair program manager.

The work was performed by the Airfields and Pavement Branch (GMA) of the Engineering Systems and Materials Division (GM), U.S. Army Engineer Research and Development Center, Geotechnical and Structures Laboratory (ERDC-GSL). At the time of publication, Dr. Timothy W. Rushing was Chief, CEERD-GMA; Dr. Gordon W. McMahon was Chief, CEERD-GM; and Pamela G. Kinnebrew, CEERD-GZT, was Technical Director for Military Engineering. The Deputy Director of ERDC-GSL was Dr. William P. Grogan, and the Director was Bartley P. Durst.

COL Bryan S. Green was the Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
foot-pounds force	1.355818	joules
gallons (U.S. liquid)	3.785412 E-03	cubic meters
horsepower (550 foot-pounds force per second)	745.6999	watts
inches	0.0254	meters
inch-pounds (force)	0.1129848	newton meters
microinches	0.0254	micrometers
microns	1.0 E-06	meters
miles per hour	0.44704	meters per second
mils	0.0254	millimeters
pounds (force)	4.448222	newtons
pounds (force) per foot	14.59390	newtons per meter
pounds (force) per inch	175.1268	newtons per meter
pounds (force) per square foot	47.88026	pascals
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.45359237	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter
pounds (mass) per cubic inch	2.757990 E+04	kilograms per cubic meter
pounds (mass) per square foot	4.882428	kilograms per square meter
pounds (mass) per square yard	0.542492	kilograms per square meter
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters
tons (force)	8,896.443	newtons
tons (2,000 pounds, mass)	907.1847	kilograms
tons (2,000 pounds, mass) per square foot	9,764.856	kilograms per square meter

1 Introduction

1.1 Background

The Airfield Damage Repair (ADR) Modernization Program was initiated to improve and expand the U.S. Air Force's (USAF's) ability to perform airfield pavement repair tasks to support the operation of modern aircraft for a variety of mission scenarios. The ADR Modernization Program includes the repair of airfields and associated paving surfaces damaged by munitions such as bombs or missile attacks. ADR encompasses all tasks required to establish, sustain, or recover airfield infrastructure to support aircraft operations in contingency environments.

In March 2002, the Joint Airfield Damage Repair Working Group recognized that legacy ADR systems had not been tested or certified for use with modern aircraft systems, specifically the C-17 aircraft. The U.S. Air Force Air Mobility Command funded the U.S. Army Engineer Research and Development Center (ERDC) to evaluate the ability of existing legacy ADR systems to support C-17 aircraft operations. Live aircraft tests conducted in 2004 identified specific shortfalls of legacy ADR systems and resulted in the beginning of the ADR Modernization Program. The specific objective of the ADR Modernization program was to develop and procure materials and equipment required to successfully meet mission requirements for the full spectrum of ADR scenarios.

Since 2005, the ADR Modernization Program has been assessing materials and equipment technology to develop repair solutions for all mission scenarios. Initial ADR development was focused on supporting missions at deployed locations or the "Open the Base" scenario. In 2008, the program's focus shifted specifically to developing methods for rapidly repairing bomb-damaged main operating bases or the "Recover the Base" scenario. The "Recover the Base" repair scenario included the repair of a large number of small craters (less than 15 ft in diameter) in 6.5 hr. Through the use of innovative materials and emerging equipment technology, a new ADR process was developed that was capable of meeting the repair requirements. This process was demonstrated in a realistic environment by airmen during the Critical Runway AssessmenT and Repair (CRATR) Joint Capability Technology Demonstration (JCTD) in 2009. The process created an assembly line procedure that divided the ADR process into the following

tasks: (1) damage assessment, (2) unexploded ordinance removal, (3) initial debris removal, (4) upheaval marking, (5) saw cutting, (6) excavating, (7) backfilling, (8) capping, and (9) final debris removal.

Upon completion of the crater repair component of the CRATR JCTD, the crater repair ADR technologies were refined and validated through a series of experiments to demonstrate the process in wet weather conditions, cold weather conditions, and for the repair of large craters using the same materials and equipment set. The results of the initial demonstrations and follow-on experiments were used to develop detailed tactics, techniques, and procedures (TTPs) as well as material and equipment specifications to support procurement and assembly of the new ADR capability.

Due to the operational constraints, especially the maximum repair timelines imposed on the development team, the ADR solution being fielded was logistically intensive, requiring a large amount of materials and equipment to ensure that airfield operations at a main operating base can be restored within 6.5 hr. As the basic repair capability was being fielded, USAF leadership began efforts to evaluate the adaptability of the basic capability for other ADR scenarios. Due to the requirement to support ADR missions around the world, it is desired to increase the agility and maneuverability of equipment utilized to perform ADR tasks. Specifically, smaller dimension material handling equipment could increase the transportability of said equipment via airborne methods. These smaller dimensioned material handling equipment options require evaluation of their ability to perform the full spectrum of ADR material movement tasks.

1.2 Objective and scope

The objectives of this project were to:

1. Identify material handling equipment with a reduced logistical footprint,
2. Compare their material handling performance in relation to currently utilized equipment,
3. Evaluate their capability to perform the full spectrum of ADR tasks, and
4. Validate published dimensional data and published load-capacity relationships.

The scope of this work included the validation of published dimensional and load-capacity characteristics as well as the evaluation of equipment

efficiency in performing ADR tasks. Specifically, the evaluation consisted of preparation of a simulated runway operating scenario (test course) and measurement of speed and maneuverability of operation in the test course.

This report provides information for the following:

1. Summary of market survey of potential equipment solutions,
2. Description of test course site,
3. Description of evaluation procedures,
4. Field evaluation results, and
5. Comparison of equipment for support of ADR tasks.

2 Market Survey

2.1 Market survey of available equipment

A market survey was conducted via an Internet search of manufacturers' websites to identify material handling equipment with a reduced logistical footprint and performance characteristics relevant to the ADR mission. For this initial data collection effort, equipment with a maximum capacity of approximately 6,000 lb was considered. Pertinent physical dimensions, operational characteristics, and load-capacity information for potential equipment solutions were assembled. Each material handling solution was evaluated for physical dimensions (ability to fit within the cargo limitations of a C-130) and load capacity (ability to perform common ADR tasks) per the published technical data sheets. A summary of identified equipment alternatives is presented in Table 1, and photographs of each solution are in Figure 1 to Figure 19.

The intent of the market survey was to obtain a representative cross section of various equipment manufacturers; therefore, the provided data should not be considered all inclusive. Other manufacturers and/or models may exist that are not included in this report.

Overall height, width, and operating weight information was collected for each telehandler and compared to published cargo characteristics of a C-130. Review of the *AMC Affiliated Contingency Load Planning Workbook 36-101 Volume 2* (2003) provides the following maximum cargo characteristics for a C-130: 102 in. height, 115 in. width, 612 in. length, and an allowable cabin load of 25,000 lb. Note it is stated that these dimensions may be exceeded after coordination with mission planning personnel. All telehandlers evaluated have dimensions less than the referenced maximum cargo characteristics for a C-130. Lifts manufactured by JCB were found to have the greatest height dimension of 99 in. or 3 in. less than the maximum cargo height. JLB manufactures the widest lift evaluated with a width of approximately 96 in. or 19 in. less than the maximum cargo width. Six of the 19 telehandlers were found to have operating weights greater than 20,000 lb, with the JLG642 having the largest operating weight at a published 22,218 lb.

Table 1. Market survey (Sheet 1 of 3).

Manufacturer	Caterpillar	Bobcat	Caterpillar	Caterpillar	Genie	Genie	Genie
Model	TL1055C	V417	TH255C	TL642C	GTH5519	GTH-636	GTH-644
Power (hp)	142.1	75	74	100.6	74	74	99
Max Travel Speed (mph)	20.4	15.5	15	20.5	16	18	17
Length to Fork Face (ft)	20.75	13.1	12.53	18.47	12.17	17.83	19.833
Width over Tires (ft)	8.42	6	5.96	7.96	5.92	7.92	8.5
Overall Height (ft)	8.42	6.5	6.7	7.83	6.33	7.83	8.92
Wheelbase (ft)	12.00	7.6	7.5	10.67	7.75	10.92	10.83
Ground Clearance (in.)	18	11.6	10.8	16.4	10	15	17
Operating Weight (lb)	34,160	10,648	11,000	21,245	10,360	17,600	21,480
Drawbar Capacity (lb)	24,000	6,970	8,700	21,000	9,200	15,100	19,200
Max Lift Height (ft)	55.1	17.1	18.3	42	19	36	44
Max Forward Reach (ft)	42.7	10.3	10.9	30	11	21.92	27
Max Lift Capacity (lb)	10,000	4,400	5,500	6,500	5,500	6,000	6,000
Max Load at Max Height (lb)	5,000	4,400	3,000	6,500	4,400	5,000	6,000
Max Load at Max Reach (lb)	2,500	1,850	1,700	700	1,900	1,500	2,000
Lifting Sack By Loops							
Rated Capacity (lb)	10000	4400	4400	6500	3000	6000	6000
Geometry Allows? (Y/N)	Y	Y	Y	Y	Y	Y	Y
Loading/Unloading Pallets							
Rated Capacity (lb)	10000	4400	4400	6500	3000	6000	6000
Geometry Allows? (Y/N)	Y	Y	Y	Y	Y	Y	Y
Loading Simplified Volumetric Mixer							
Rated Capacity (lb)	8000	---	--	4000	--	3000	4000
Geometry Allows? (Y/N)	Y	N	N	Y	N	Y	Y
Dry Fill Small Crater (<15 ft)							
Rated Capacity (lb)	10000	2500	2000	6500	3000	6000	6000
Geometry Allows? (Y/N)	Y	Y	Y	Y	Y	Y	Y
Max Forward Reach with Sack (ft)	24	7	6.5	18	7	15	22
Capable of All Activities?	Y	N	N	Y	N	Y	Y

Table 1. Market survey (Sheet 2 of 3).

Manufacturer	JCB	JCB	JLG	JLG	Manitou	Manitou	Manitou
Model	506-36	507-42	G5-18A	642	MLT625 75H	MT625H	MT5519
Power (hp)	74	74	74	110	75	75	68
Max Travel Speed (mph)	15.5	15.5	15	21	18.6	15.5	15
Length to Fork Face (ft)	19.42	21.25	12.53	18.92	12.76	12.8	12.33
Width over Tires (ft)	7.83	7.83	5.96	8.08	5.94	5.94	5.92
Overall Height (ft)	8.25	8.25	6.3	8	6.56	6.3	6.33
Wheelbase (ft)	10.33	10.33	7.5	11.25	7.55	7.55	7.5
Ground Clearance (in.)	15.5	15.5	10.8	17	15	13	14
Operating Weight (lb)	20,270	21,300	11,000	22,218	10,873	10,582	10,000
Drawbar Capacity (lb)	N/A	N/A	8,700	20,255	7,284	7,980	N/A
Max Lift Height (ft)	36.33	42	18.33	42	19.36	19.19	19.08
Max Forward Reach (ft)	24	28	10.92	29	10.83	11.15	11
Max Lift Capacity (lb)	6,000	7,000	5,500	6,600	5,500	5,500	5,500
Max Load at Max Height (lb)	6,000	6,000	4,400	6,000	4,400	4,400	3,000
Max Load at Max Reach (lb)	1,800	1,600	1,850	1,000	1,760	1,760	1,850
Lifting Sack By Loops							
Rated Capacity (lb)	6000	7000	3000	6600	3300	3300	4000
Geometry Allows? (Y/N)	Y	Y	Y	Y	Y	Y	Y
Loading/Unloading Pallets							
Rated Capacity (lb)	6000	7000	3000	6600	3300	3300	4000
Geometry Allows? (Y/N)	Y	Y	Y	Y	Y	Y	Y
Loading Simplified Volumetric Mixer							
Rated Capacity (lb)	4000	6000	--	4000	--	--	--
Geometry Allows? (Y/N)	Y	Y	N	Y	N	N	N
Dry Fill Small Crater (<15 ft)							
Rated Capacity (lb)	6000	7000	2000	6600	2600	2600	3000
Geometry Allows? (Y/N)	Y	Y	Y	Y	Y	Y	Y
Max Forward Reach with Sack (ft)	15	21	7	18	7	7	8
Capable of All Activities?	Y	Y	N	Y	N	N	N

Table 1. Market survey (Sheet 3 of 3).

Manufacturer	Manitou	Manitou	Merlo	Merlo	Merlo	New Holland
Model	MT6034	MT6642	P25.6	P28.8	P32.6	LM6.32
Power (hp)	74	115	75	101	101	110
Max Travel Speed (mph)	20.2	18.8	22	25	25	25
Length to Fork Face (ft)	16	19.08	12.58	13.75	13.67	15.94
Width over Tires (ft)	7.83	8	5.83	6.42	6.42	7.98
Overall Height (ft)	7.83	7.83	6.17	7	7	8.03
Wheelbase (ft)	9.17	10	8	8.75	8.75	9.83
Ground Clearance (in.)	14	16	9	14	14	16.3
Operating Weight (lb)	15,100	22,000	10,000	14,100	13,100	17,494
Drawbar Capacity (lb)	N/A	N/A	N/A	N/A	N/A	N/A
Max Lift Height (ft)	34.25	42	19.33	26.75	20.75	20.6
Max Forward Reach (ft)	23.25	28.25	10.67	17.25	11.17	11
Max Lift Capacity (lb)	6,000	6,600	5,500	6,170	7,050	7,054
Max Load at Max Height (lb)	4,000	6,600	3,300	1,300	2,700	7,054
Max Load at Max Reach (lb)	900	1,000	2,200	1,300	2,700	2,970
Lifting Sack By Loops						
Rated Capacity (lb)	6000	6600	4400	4500	5500	6600
Geometry Allows? (Y/N)	Y	Y	Y	Y	Y	Y
Loading/Unloading Pallets						
Rated Capacity (lb)	6000	6600	4400	4500	5500	6600
Geometry Allows? (Y/N)	Y	Y	Y	Y	Y	Y
Loading Simplified Volumetric Mixer						
Rated Capacity (lb)	3000	5000	--	1300	--	--
Geometry Allows? (Y/N)	Y	Y	N	****	N	N
Dry Fill Small Crater (<15 ft)						
Rated Capacity (lb)	5000	6600	3300	3300	4000	4400
Geometry Allows? (Y/N)	Y	Y	Y	Y	Y	Y
Max Forward Reach with Sack (ft)	13	18	7.5	9.5	8	10
Capable of All Activities?	Y	Y	N	N	N	N

The ability of each telehandler to lift an approximately 3,000-lb super sack on a pallet was evaluated. For this action, an extension of 5.5 ft and a lift height of 5 ft was selected as representative of loading/unloading palletized super sacks from a typical flatbed trailer. A review of the load charts indicated each telehandler was capable of performing this task. Two telehandlers (Genie GTH5519 and JLG G5-18A) were approaching their rated capacity (3,000 lb) performing a palletized lift operation. All telehandlers had the available geometry (lift height and forward reach) to perform this task.

The ability of each telehandler to lift a 3,000-lb super sack by the bag's integrated lifting loops was also evaluated. An extension of 5.5 ft and a lift height of 5.25 ft was selected as representative for this action. A review of the load charts indicated that each telehandler was capable of performing this task. Two telehandlers (Genie GTH5519 and JLG G5-18A) were approaching their rated capacity (3,000 lb) performing an integrated loop lift operation. All telehandlers had the available geometry (lift height and forward reach) to perform this task.

The ability of each telehandler to lift a 3,000-lb super sack by the bag's integrated lifting loops for a dry fill placement of a small crater repair was evaluated. A small crater was defined as being ≤15 ft in diameter; therefore, an extension of 7.5 ft (distance from the edge of the crater to the center) and a lift height of 5.25 ft was selected as representative. Five telehandlers (Bobcat V417, Caterpillar TH255C, JLG 65-18A, Manitou MLT625 75H, and Manitou MT625H) did not have the rated capacity to perform this operation All telehandlers had the available geometry (lift height and forward reach) to perform this task. Additionally, the maximum forward reach with a 3,000-lb super sack was determined for each telehandler. The Bobcat V417 was reported to have the least loaded forward reach at approximately 6.5 ft with the Caterpillar TL 642C and the JCB 507-42 having the greatest loaded forward reach at approximately 21 feet.

The ability of each telehandler to lift a 3,000-lb super sack by the bag's integrated lifting loops for loading the simplified volumetric mixer was also evaluated. For this action, an extension of 12 ft and a lift height of 15 ft was selected. This operation was found to be a limiting operation, with eight of the 19 handlers capable of performing this task. Ten handlers were found to lack the available geometry (lift height and forward reach) and one handler was found to lack the rated capacity to perform this task. Two

handlers (Genie GTH-636 and Manitou MT6034) were approaching their rated capacity performing the mixer loading operation.

The ability and capacity of each telehandler to act as a tow vehicle was evaluated. Nine of the telehandlers reviewed were found to have some towing capabilities (drawbar capacity). Of the telehandlers capable of towing, the Caterpillar TL 642C was found to have the greatest documented drawbar capacity at 21,000 lb with the Bobcat V417 having the least drawbar capacity rated at 6,970 lb.

Adaptability (the ability to operate attachments other than standard forks) for each telehandler was evaluated. Eight telehandlers were found to possess the ability to operate attachments other than standard forks. The most versatile telehandlers were found to be the Bobcat V417, JLG G5-18A, and the New Holland LM6.32, which were advertised as capable of operating various skid-steer type attachments through the use of an optional skid-steer attachment plate and/or optional additional hydraulic ports. The other telehandlers with documented attachment capabilities were limited to a combination of various forks, buckets, and/or sweepers.

Based on a review of published dimensional and load-capacity data, selected lower capacity telehandlers are capable of transport via C-130 and operation of typical ADR tasks. Telehandlers found capable of performing all typical ADR tasks include Caterpillar TL642C, Genie GTH-636, JCB 506-36, JCB 507-42, JLG 642, Manitou MT6034, and Manitou MT6642. The ability of each telehandler to lift a 3,000-lb super sack for loading the simplified volumetric mixer was found to be the limiting operation generally due to the lack of available geometry.

In order to validate the results of the market survey, selected telehandlers were field evaluated in terms of these physical dimensions and load-capacity relationships. Results of field validation are presented in Chapter 3.

Figure 1. Caterpillar TL1055C (www.cat.com).

Figure 2. Bobcat V417 (www.bobcat.com).

Figure 3. Caterpillar TH255C.

Figure 4. Caterpillar TL642C.

Figure 5. Genie GTH5519.

Figure 6. Genie GTH636.

Figure 7. Genie GTH644.

Figure 8. JCB 506-36 (www.jcbna.com).

Figure 9. JCB 507-42.

Figure 10. JLG G5-18A (www.jlg.com).

Figure 11. JLG 642.

Figure 12. Manitou MLT625 75H (www.manitou.com).

Figure 13. Manitou MT625H (www.manitou.com).

Figure 14. Manitou MT5519 (www.manitou.com).

Figure 15. Manitou MT6034 (www.manitou.com).

Figure 16. Manitou MT6642.

Figure 17. Merlo P32.6 (www.ams-merlo.com).

Figure 18. Merlo P32.6 (www.ams-merlo.com).

Figure 19. New Holland LM 6.32 (www.agriland.ie).

2.2 Market survey of potential integrated lifting equipment

A market survey was performed to determine if commercial lifting mechanisms are available that could potentially be integrated with the simplified volumetric mixer. This could provide for a reduction in manpower or equipment needs in an ADR scenario, or provide for the reallocation of manpower and equipment currently required to load concrete repair materials and accelerate other portions of the airfield damage repair process.

Integrated lifting mechanisms utilized in other industries were focused on for this survey. Industries investigated included the forestry industry, waste management industry, and agricultural/mechanical industry. It was the intent of this survey, based on the technical data sheets, to present the lifting capabilities, operational limitations, and potential integration challenges of the selected commercial equipment. This summary is presented as an introduction to the identified commercial lifting equipment; however, field evaluation was outside the scope of this work. It is recommended that if these lifting solutions are pursued, field evaluations be conducted to verify operational constraints.

Forestry Industry. The first integrated lifting solution identified was a knuckle-boom loader (see Figure 20) commonly utilized in the forestry industry. These loaders can be stand-alone trailer mounted, behind-cab truck mounted, or trailer-tongue mounted. The version identified as the most promising for the current simplified volumetric mixer would be the trailer-tongue mounted version. The loaders consist of an A-frame design, extendable outriggers, and an elevated operator platform. Weights of the knuckle-boom loaders identified range from approximately 5,000 lb to 7,000 lb.

Figure 20. Knuckle-boom loader (www.prenticeforestry.com).

Potentially positive aspects of an integrated knuckle-boom loader include:

- Trailer-tongue mounting would provide for self-contained lifting capabilities on the simplified volumetric mixer.
- An elevated operator platform would allow for ease of alignment of the super sacks over the bag breaking mechanism.
- The driver could exit the vehicle during material placement and act as the loader operator (potential reduction in manpower).

- The super sacks could be staged using a skid-steer loader and loaded with the knuckle-boom loader, allowing for either the elimination or reallocation of an extendable boom forklift to perform other tasks in an ADR scenario.
- The knuckle-boom loader could potentially be utilized to mobilize loaded super sacks over a prepared crater for the dry-fill crater repair method.

Potential challenges associated with integrating a knuckle-boom loader include:

- Mounting the loader on the trailer tongue would likely require relocation of the trailer-lifting jack and hydraulic power pack.
- Mounting the loader on the trailer tongue would add load likely requiring a structural analysis and potential redesign and/or stiffening of the tongue.
- Hydraulic flows and capacities would require evaluation to determine if additional hydraulic power packs and/or other drive mechanisms are needed for operation.
- A capture mechanism and/or integrated loop redesign would be required to allow for operation by a single driver.

Waste Management Industry. Lifting devices used in the waste management industry were investigated as potential integrated lifting solutions. Specifically identified were front-lifting hydraulic arms (see Figure 21) commonly observed to empty steel refuse collection containers. Available literature indicates these mechanisms are capable of lifting up to 10,000 lb, well beyond that required for nominal 3,000-lb super sacks.

Positive aspects of a waste management loader include:

- Sufficient capacity to lift single or multiple super sacks, and
- Front-loading design could allow for single operator use.

Potential challenges associated with a waste management loader include:

- The simplified volumetric mixer would require conversion to a truck-mounted option in order to utilize similar operational characteristics of a waste management truck.
- The currently utilized super sacks and/or the integrated lifting arms would require extensive modification for operational efficiency.
- The current operational procedures would likely require modification (i.e., transport material to truck vs. truck mobilize to material).

Figure 21. Waste management lifting (www.mcneiluscompanies.com).

Agricultural/Mechanical Industry. The final equipment solution investigated was a telescoping boom crane (see Figure 22), sometimes referred to as a “jib crane.” These cranes are typically utilized from a fixed platform such as a truck or industrial floor. Operational characteristics vary from electrical powered to fully hydraulic power with capacity ranging from 2,000 lb to 14,000 lb, depending on the model selected.

Figure 22. Telescopic boom crane (www.tigercrane.com).

Potentially positive aspects of an integrated jib crane include:

- Trailer-tongue mounting would provide for self-contained lifting capabilities on the simplified volumetric mixer.
- Some models are equipped with remote control operation allowing for a single operator to hook super sacks.
- The driver could exit the vehicle during mixture placement and act as the loader operator (potential reduction in manpower).
- The super sacks could be staged using a skid-steer loader and loaded with the jib crane, allowing for either the elimination or reallocation of an extendable boom forklift to perform other tasks in an ADR scenario.
- The jib crane could potentially be utilized to mobilize loaded super sacks over a prepared crater for the dry-fill crater repair method.

Potential challenges associated with integrating a knuckle-boom loader include:

- Mounting the loader on the trailer tongue would likely require relocation of the trailer-lifting jack and hydraulic power pack.
- Mounting the loader on the trailer tongue would add load likely requiring a structural analysis and potential redesign and/or stiffening of the tongue.
- Hydraulic flows and capacities would require evaluation to determine if additional hydraulic power packs and/or other drive mechanisms are needed for operation.

Based on the review of available literature, the knuckle-boom loader and the jib crane could potentially be effective as integrating lifting capabilities with the current simplified volumetric mixer. Both options could be mounted near the tongue of the current mixer, but would require some relocation and/or modification of currently arranged hydraulic mixer components. Other factors that would need to be considered include structural integrity of the trailer frame, operational lift capacities, and transportability. The integration of a lifting mechanism similar to that utilized in the waste management industry would likely require extensive modification and/or redesign of the simplified volumetric mixer and the material storage units (super sacks) to be an effective operations solution.

3 Field Evaluation and Results

3.1 Field evaluation

A field evaluation was performed of selected material handling solutions in a realistic environment to determine their ability to perform typical ADR tasks. The field evaluation consisted of validation of the manufacturers' published technical data and evaluation of speed and maneuverability.

3.1.1 Validation of published technical data

All selected equipment was measured for length, width, height, and ground clearance. Length measurements were performed with and without standard fork attachments. Width measurements were based on the widest observable location on the equipment. Height measurements were made from surface to the uppermost portion on the parked machine, to include any safety accessories such as beacons. Ground clearance measurements were based on the lowest identifiable portion of the equipment. All measurements were made with the equipment parked on a reasonably level paved surface.

Published load-capacity curves are based on stability/overturn tests as outlined in American National Standards Institute (ANSI) B56.6 (2011). This test consists of placing equipment with a standard load on a tilting platform. From this standard, overturn is defined as the point at which the truck completely tips over, not the point at which a wheel loses contact with the platform. **Note: For this study, load-capacity limit is defined as the point at which the machine becomes off-balance (i.e., the point at which the rear wheels are no longer in contact with the ground surface).**

To validate the load-capacity curves and determine the operational limits of each equipment solution, various lifting and extension exercises were performed. Initially, it was intended to use an approximate 3,000-lb super sack containing rapid-setting concrete material for the exercise. It was found that after three to four lifts by the bags' integrated loops, the abrasive nature of the lift forks could lead to loop failure. Generally speaking, any abnormality in the fork edges would act as a serrated knife and cut through the lifting loops. In order to minimize variability

associated with using multiple super sacks during the course of the study, a fixture was designed to allow for the simulation of lifting and maneuvering a super sack through the various ADR scenarios. The fixture used for the study is shown in Figure 23. Steel weights were added to the fixture to achieve the nominal 3,000-lb loading required and a hanging mechanism consisting of a combination of lifting straps and safety hooks were used to simulate the operational characteristics of a loaded super sack. The validation exercises using the simulated super sack are discussed in further detail below.

Pallet lift for loading/unloading. The palletized simulated super sack was lifted from the ground to a nominal height (see Figure 24). The boom was extended to the point the machine became off balance, and the maximum extension was recorded. Secondly, the simulated super sack was lifted to its maximum vertical angle (see Figure 25). The boom was extended to the point the machine became off balance, and the maximum extension was recorded.

Loop lift for dry-fill method. The simulated super sack was lifted by its integrated lifting straps to a nominal height, and the boom was extended to the point the machine became off balance simulating the dry-fill crater method (see Figure 26). The maximum horizontal extension was recorded.

Loop lift for loading simplified volumetric mixer. The simulated super sack was lifted by its integrated lifting straps to a minimum horizontal extension of 12 ft and a minimum vertical extension of 15 ft to simulate loading the simplified volumetric mixer (see Figure 27). The horizontal and vertical dimensions were extended beyond the minimums to the point the machine became off balance. The ability of the machine to load the volumetric mixer was noted as pass/fail, and dimensions beyond the minimums (if applicable) were noted.

Figure 23. Fixture used to simulate loaded super sack.

Figure 24. Palletized lift for maximum horizontal extension.

Figure 25. Palletized lift for maximum vertical extension.

Figure 26. Loop lift for maximum horizontal extension.

Figure 27. Loop lift for loading mixer maximum horizontal and vertical extension.

3.1.2 Test course layout

Each machine was evaluated for speed and maneuverability in a realistic environment. To simulate an airfield runway operating scenario, an approximately 75-ft by 200-ft paved area located behind the ERDC Hanger 2 Test Facility was used for the timed tests. A test course was designed to simulate unloading and staging super sacks, retrieving a super sack for the dry-fill method, and loading a super sack in the volumetric mixer. In order to limit human variability, a single operator was used to perform each task on each machine. Prior to performing each timed task, the operator was provided sufficient time to become familiar with the operation and handling of each machine. The test course layout is shown in Figure 28. A description of each timed exercise is provided below.

Palletized lift. Five pallets loaded with a total of approximately 3,000 lb each were located in the staging area. The operator was required to begin at the start location as shown in Figure 28. Timing began when the operator crossed the starting line. The operator was required to place the five loaded pallets within the bag unloading test area. Time was stopped when the last loaded pallet reached the bag unloading test area. The exercise was performed three times to obtain an average time.

Loop lift for the dry-fill method. For this event, timing started when the operator crossed the starting line. The operator was required to retrieve the simulated super sack by the integrated lifting straps from the staging area and mobilize to the simulated crater area. The simulated crater boundaries consisted of a 15-ft by 15-ft square on the asphalt pavement. The operator was required to stop at the painted line and to extend the lifted super sack to the middle of the simulated crater area. A traffic safety cone was located in the center of the simulated crater area and timing ceased when the operator struck the safety cone with the lifted simulated super sack. This exercise was performed three times to obtain an average time.

Loop lift for loading the simplified volumetric mixer. For this event, the operator was required to retrieve the simulated super sack from the staging area and progress to the simplified volumetric mixer located near the end of the course. The operator was required to lift the super sack above the mixer to the loading position. A visual indicator, a plastic road safety cone, was attached to the bag breaker mechanism on the mixer, and timing ceased when the super sack struck the road safety cone. A total of three trials were conducted to obtain an average time.

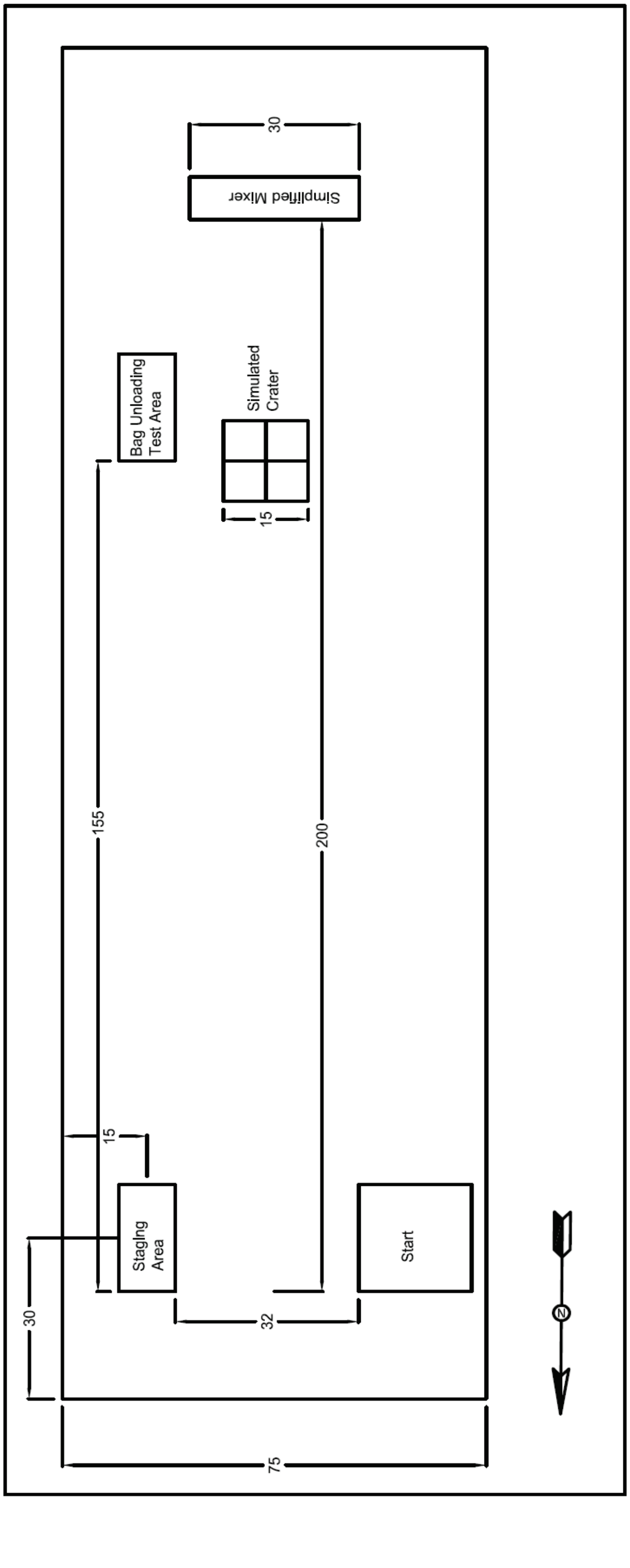


Figure 28. Test course layout.

3.2 Field evaluation results

3.2.1 Results of physical dimension validation

Results of the field measurement of physical dimensions are shown in Table 2. Lengths measured to the fork face were found to be greater than published lengths in most cases and exceeded published lengths by approximately 1.5 in. to 8 in. This is likely due to the inclusion of tow hitches in the field-measured dimensions. All field-verified length measurements (including fork length) were less than 612 in.

Table 2. Results of field validated dimensions.

Manufacturer	Model	Measured/Published	Length (in., with forks)*	Length (in., without forks)	Width (in.)	Height (in.)	Ground Clearance (in.)
Caterpillar	TL1055C	Measured	330.00	257.00	100.50	102.50	17.50
		Published	321.00	249.00	101.00	101.00	18.00
Caterpillar	TL642C	Measured	278.00	224.00	102.00	95.00	15.50
		Published	281.60	221.64	95.52	93.96	16.40
Caterpillar	TH255C	Measured	203.00	152.00	71.00	78.00	12.00
		Published	198.36	150.36	71.52	80.40	10.80
Manitou	MT6642	Measured	278.00	228.00	100.00	93.00	17.00
		Published	276.96	228.96	96.00	93.96	16.00
Genie	GTH5519	Measured	205.00	151.00	73.50	79.25	9.25
		Published	206.04	146.04	71.04	75.96	10.00
Genie	GTH636	Measured	263.00	213.00	98.75	94.75	15.00
		Published	261.96	213.96	95.04	93.96	15.00
Genie	GTH644	Measured	316.50	246.00	102.00	106.00	15.00
		Published	310.00	238.00	102.00	107.04	17.00
JLG/Skytrack	6042	Measured	278.00	227.00	98.00	99.00	16.00
		Published	268.00	220.00	99.00	102.00	16.00
JCB	507-42	Measured	309.50	258.50	98.00	102.00	16.75
		Published	303.00	255.00	94.00	99.00	15.50

*Published values vary based on fork type

Width measurements were made at the widest observable location, which included wheel fenders. Items that could be folded in, such as side view mirrors, were not included in the width measurement. Width measurements were found to be greater than published values in most cases, exceeding the published data by approximately 2.5 in. to 6.5 in. All field-verified width measurements were less than 115 in.

Height measurements were made to the tallest observable location to include safety beacons and fan housings. Height measurements exceeded the published data approximately ¾ in. to 3.5 in. Three telehandlers, i.e., CAT TL1055C, Genie GTH 644, and JCB 507-42, were found to exceed the maximum 102-in.-height requirement.

3.2.2 Results of load-capacity validation

Results of the load-capacity validation are presented in Table 3. It was found that the measured extensions with a nominal load of 3,000 lb exceeded the published values ranging from approximately 0.5 ft up to nearly 7 ft. The JLG/Skytrack 6042 was found to have the largest difference in published and measured values with the horizontal components of each lift exceeding the published values by 5 ft to 7 ft. All other lifts evaluated were found to have measured values that agreed with published values within 1 ft to 2 ft.

Table 3. Validation of load capacity.

Lift Description			Pallet Lift, ft		Loop Lift, ft	Mixer Lift, ft	
Manufacturer	Model	Measured/Published	Max Horizontal	Max Vertical	Max Horizontal	Max Horizontal	Max Vertical
Caterpillar	TL1055C	Measured	25.25	54.08	25.83	23.58	20.67
		Published	24.00	52.50	23.50	23.00	21.00
Caterpillar	TL642C	Measured	18.75	41.75	19.92	19.67	18.42
		Published	18.50	42.00	18.00	17.50	18.00
Caterpillar	TH255C	Measured	7.58	16.75	7.75	6.50	8.50
		Published	7.00	16.00	6.50	6.50	10.00
Manitou	MT6642	Measured	20.50	41.67	20.58	19.92	18.75
		Published	19.00	42.00	19.00	18.00	19.00
Genie	GTH5519	Measured	7.17	18.50	7.42	6.50	8.00
		Published	7.00	19.00	7.00	7.00	11.50
Genie	GTH636	Measured	17.58	35.92	18.00	17.33	17.50
		Published	15.50	36.00	15.50	15.00	16.50

Lift Description			Pallet Lift, ft		Loop Lift, ft	Mixer Lift, ft	
Manufacturer	Model	Measured/Published	Max Horizontal	Max Vertical	Max Horizontal	Max Horizontal	Max Vertical
Genie	GTH644	Measured	21.00	44.00	21.25	17.50	16.42
		Published	21.00	43.00	21.00	17.00	18.00
JLG/Skytrack	6042	Measured	23.75	41.70	24.92	23.08	20.25
		Published	18.00	41.50	18.00	18.00	19.00
JCB	507-42	Measured	22.17	41.70	22.83	21.40	18.60
		Published	21.00	42.00	21.00	20.50	19.00

3.2.3 Results of timed events

Analysis of all collected data for the palletized lift exercise yielded an average time of 312.94 sec with a standard deviation of 29.32 sec required to complete the test cycle. The Caterpillar TL1055C (Control) was found to be the most efficient in the palletized lift exercise with an average time of 264.55 sec. The Genie GTH 5519 was found to be the least efficient in the palletized movement with an average time of 353.39 sec. It was noted that the operator stated that the fork tips were difficult to see on approach to each pallet due to the small dimensions of the equipment. Of the ~6,000-lb capacity telehandlers, the Caterpillar TL642C was found to be the most efficient with an average time of 283.12 sec, and the Manitou MT6642 was found to be the least efficient with a time of 341.25 sec. Average times for the palletized lift exercise for each telehandler are presented in Figure 29.

The loop lift dry-fill exercise resulted in an overall average time of 40.93 sec with a standard deviation of 2.30 sec for all telehandlers evaluated. The test results indicate the JLG/Skytrack 6042 was the most efficient telehandler evaluated with an average time of 38.15 sec. The Caterpillar TL642C was found to be the least efficient with an average time of 44.95 sec. The Caterpillar TL1055 C ranked number four of the nine telehandlers evaluated for this exercise. The Caterpillar TH255c and the Genie GTH5519 (both with a total rated capacity of 5,500 lb) were not capable of performing the dry-fill crater exercise. The exercise was attempted with each telehandler but it was found just at or prior to reaching the road safety cone in the simulated crater, the rear wheels would lose contact with the ground. Overall, times for this event were found to be relatively close ranging from 38.15 sec to 44.95 sec. Average times for the loop lift dry-fill exercise are presented in Figure 30.

Figure 29. Palletized exercise average time.

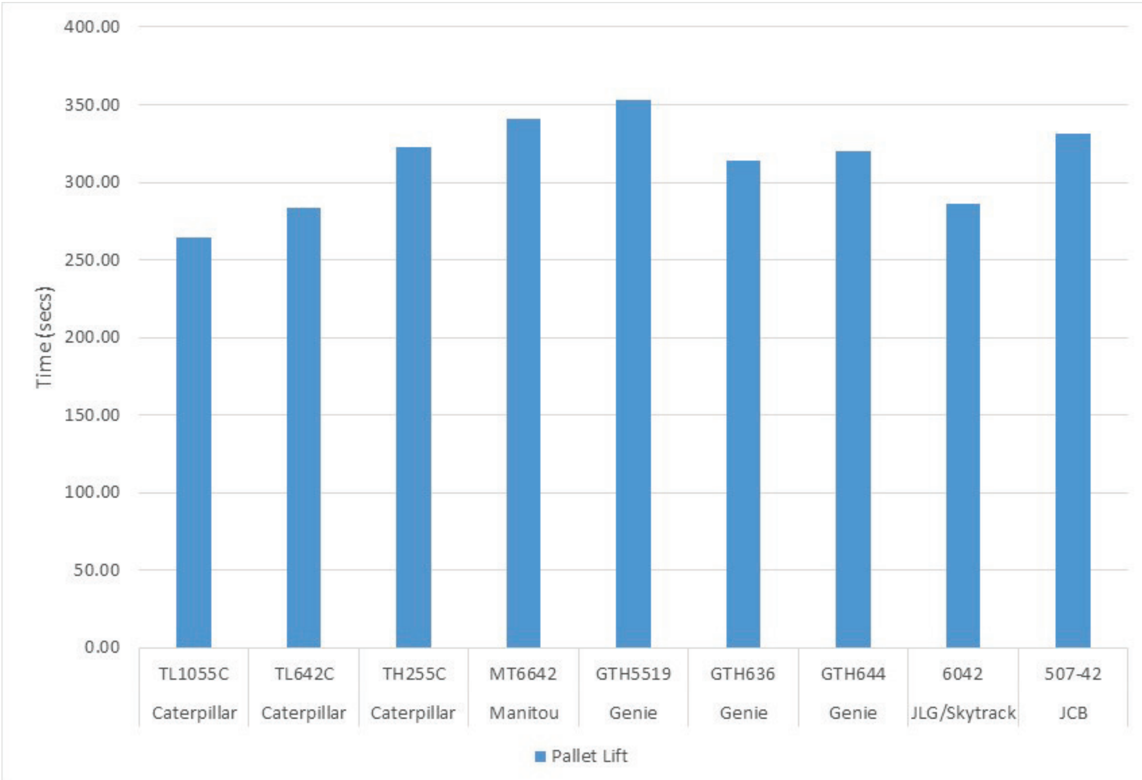
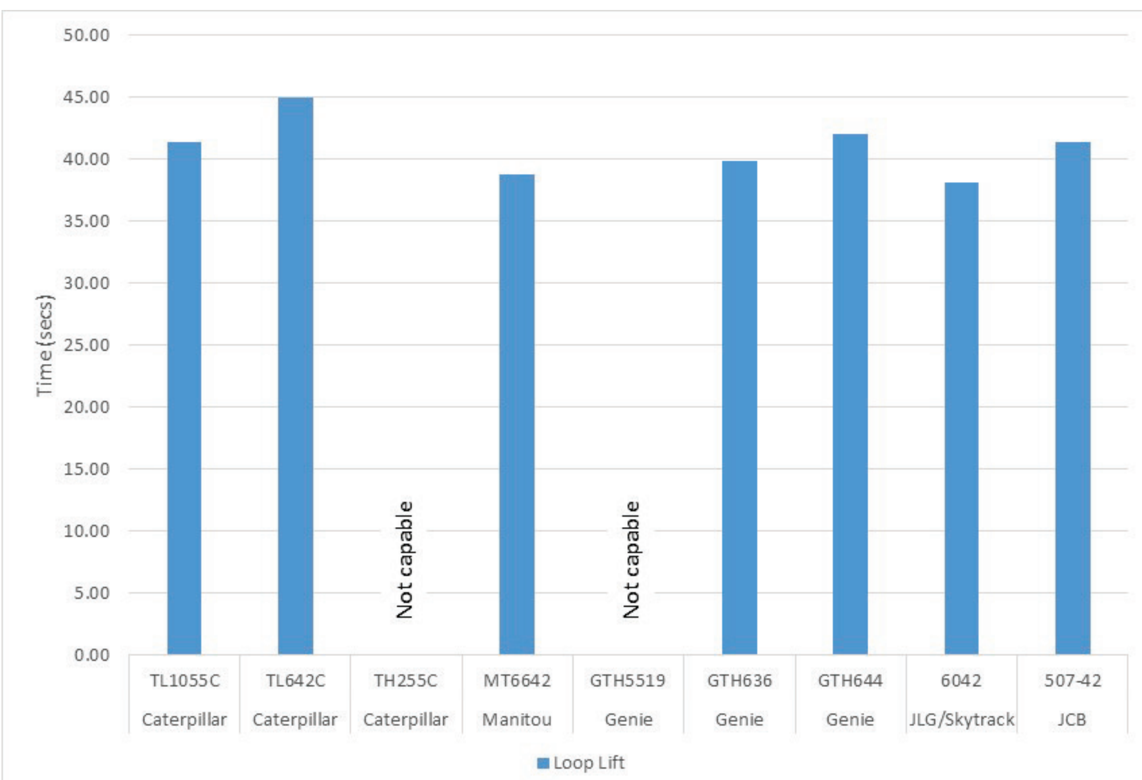
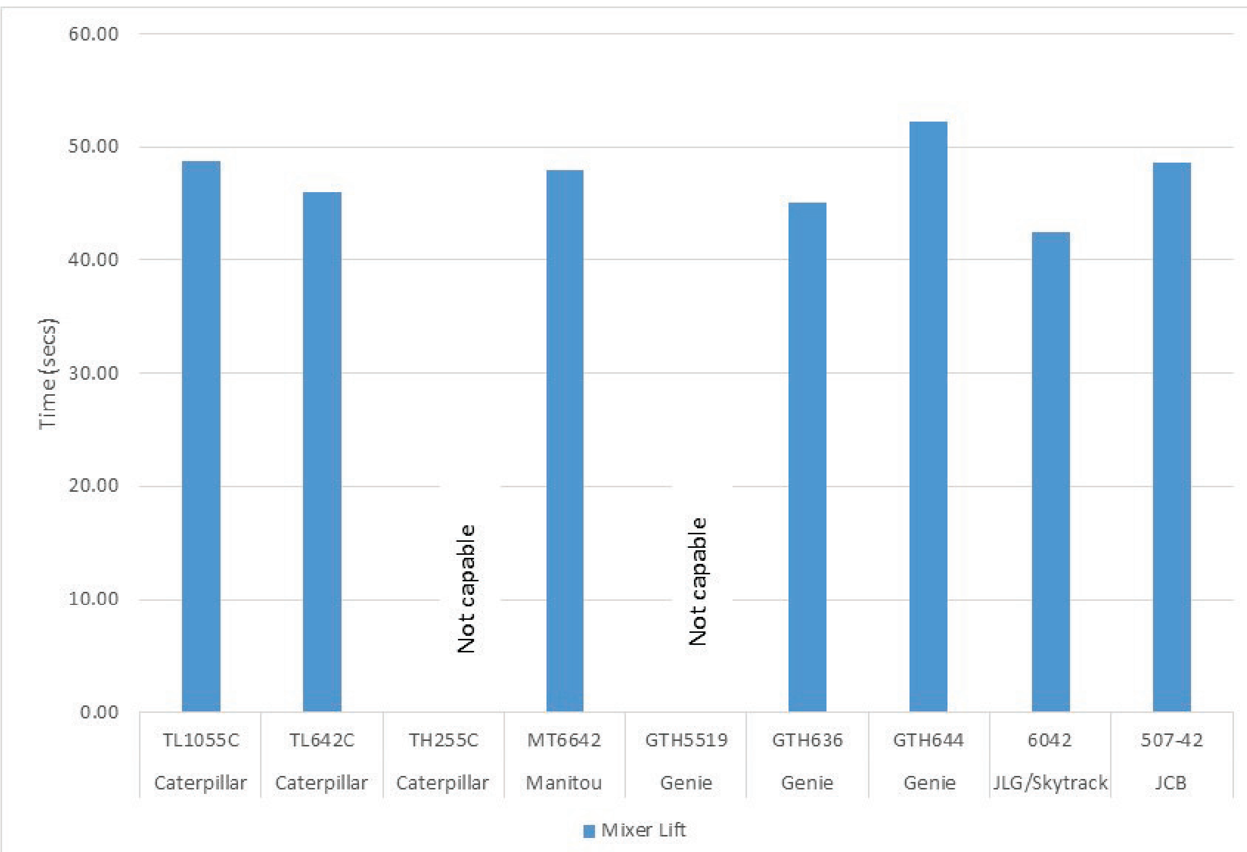


Figure 30. Loop lift dry fill exercise average time.



An overall average time of 47.29 sec with a standard deviation of 3.12 sec was measured for the simplified volumetric mixer exercise. The JLB/Skytrack 6042 was found to be the most efficient with an average time of 42.46 sec followed by the Genie GTH636 and Caterpillar TL642C with average times of 45.12 sec and 45.94 sec, respectively. Test results show the Genie GTH644 to be the least efficient for this exercise with an average time of 52.21 sec. The Caterpillar TL1055C ranked number six of the nine telehandlers evaluated for this exercise. The Caterpillar TH255C and Genie GTH5519 were not capable of performing the simplified volumetric mixer exercise, limited both by available geometry and load capacity. Overall, times for this event ranged from 42.46 sec to 52.21 sec. Average times for the mixer lift exercise are presented in Figure 31.

Figure 31. Simplified volumetric mixer exercise average time.



3.2.4 Efficiency Rating and Logistical Savings

A normalized total efficiency rating (ER) was calculated to determine an overall measure of each telehandler's performance characteristics in the timed events and to allow meaningful comparison between individual

telehandlers. The normalized total efficiency rating was calculated using the following equation:

$$ER = \frac{Average\ PT}{PT} + \frac{Average\ DLT}{DLT} + \frac{Average\ SVMT}{SVMT}$$

where:

ER = normalized total efficiency rating
PT = palletized exercise time, sec
DLT = loop lift dry-fill exercise time, sec
$SVMT$ = simplified volumetric mixer exercise time, sec

Telehandlers with an efficiency rating of 3.0 would be considered average performers. An efficiency rating greater than 3.0 would indicate an above average performer (more efficient) and an efficiency rating less than 3.0 would be considered a below average performer. The JLG/Skytrack 6042 was found to be the most efficient with a total efficiency rating of 3.28 followed by the Caterpillar TL1055 C with a total efficiency rating of 3.14. Note efficiency ratings were not calculated for the Caterpillar TH255C and Genie GTH5519, as each was not capable of performing the loop lift dry-fill exercise and simplified volumetric mixer exercise. Normalized total efficiency ratings (sorted from highest rating to lowest rating) are presented in Table 4.

Table 4. Normalized total efficiency ratings.

Manufacturer	Model	Efficiency Rating (ER)
JLG/Skytrack	6042	3.28
Caterpillar	TL1055C	3.14
Genie	GTH636	3.07
Caterpillar	TL642C	3.05
Manitou	MT6642	2.96
JCB	507-42	2.90
Genie	GTH644	2.86
Caterpillar	TH255C	NC*
Genie	GTH5519	NC*

*NC = not calculated

Potential logistical savings were quantified by calculating the volume and weight savings of each evaluated telehandler as compared to the Caterpillar TL1055 C Control. Field-measured dimensions were used to calculate total volume in terms of cubic feet. Due to the potential of various fork lengths available, volumes and percent volume reductions were based on measured lengths without forks included. Volume was simply calculated using the overall length (without forks), height, and width measurements made in the field. Weights presented are based on the manufacturer's published operating weights. Potential logistical savings are presented in Table 5.

Table 5. Potential logistical savings.

Manufacturer	Model	Volume (ft^3)[1]	Volume Reduction (%)	Weight (lb)[2]	Weight Reduction (%)
Caterpillar	TL1055C	1532.1	--	34,160	--
Caterpillar	TL642C	1256.1	18.0	21,245	37.8
Caterpillar	TH255C	487.1	68.2	11,000	67.8
Manitou	MT6642	1227.1	19.9	22,000	35.6
Genie	GTH5519	509.0	66.8	10,360	69.7
Genie	GTH636	1153.3	24.7	17,600	48.5
Genie	GTH644	1539.2	-0.5	21,480	37.1
JLG/Skytrack	6042	1274.5	16.8	22,218	35.0
JCB	507-42	1495.4	2.4	21,300	37.6

[1]Volumes based on measured length without forks

[2]Weights are based on manufactures published operating weights

Of the telehandlers capable of performing all ADR tasks, the Genie GTH636 was found to provide the greatest volume reduction with a total reduction of 24.7%. The Manitou MT6642, Caterpillar TL642C, and JLG/Skytrack had the next highest volume reductions with values of 19.9%, 18.0%, and 16.8%, respectively. The JCB 507-42 had a relatively small reduction at 2.4% and the Genie GTH644 had a volume approximately equal to the Caterpillar TL1055C. Note that the 5,500-lb capacity telehandlers had significant volume reductions (~67%) but were not capable of performing all the ADR exercises.

The Genie GTH636 was found to provide the greatest weight reduction of the telehandlers capable of performing all ADR exercises with a reduction of 48.5%. The remaining ~6,000-lb capacity telehandlers had weight reductions ranging from approximately 35-38%.

4 Conclusions and Recommendations

ERDC performed a market survey and field evaluation of material handling equipment with a reduced logistical footprint to evaluate their capability to perform typical tasks associated with an ADR operating scenario. Selected telehandlers were evaluated to verify published dimension data and validate load-capacity relationships. Loading the simplified volumetric mixer was found to be the limiting operation identified. The following sections present the conclusions and recommendations resulting from the study of smaller capacity telehandlers.

4.1 Conclusions

4.1.1 Market surveys

- Results of the market survey of currently available telehandlers indicate lower capacity equipment solutions are capable of air transport via C-130 and performance of all ADR tasks.
- Results of the market survey indicate a minimum-rated capacity of 6,000 lb is required to perform all ADR tasks.
- It was found that loading the simplified volumetric mixer was the limiting operation in the ADR scenario due to a lack of available geometry on the smaller lifts.
- Potential integrated lifting solutions were identified and an integrated knuckle-boom and jib crane were found to be the most promising adaptation to the simplified volumetric mixer.

4.1.2 Field evaluation

- Field validated length measurements were found to be greater than published values in most cases. All telehandlers evaluated were found to have length measurements less than 612 in.
- Field validated width measurements were found to be greater than published values in most cases. All telehandlers evaluated were found to have width measurements less than 115 in.
- Field validated height measurements were found to be greater than published values in most cases. Three telehandlers exceeded the 102-in. height limitation (CAT TL1055C, Genie GTH 644, and JCB 507-42).

- Measured boom extensions were found to exceed the published values in most cases on the order of 1-2 ft. The JLG/Skytrack 6042 had the largest difference in measured and published load capacity observed.
- Results of the timing events indicate the smaller telehandlers can perform the ADR tasks at or near the times observed with the 10,000-lb control telehandler.
- The 5,500-lb-capacity telehandlers (CAT TH255C and Genie GTH5519) were not capable of performing the dry-fill crater maneuver or loading the simplified volumetric mixer.
- It was found that the 5,500-lb capacity telehandlers were difficult for the operator to align due to the lack of ability to see the fork tips.
- The most efficient machines evaluated in the timed events were found to be the JLG/Skytrack 6042, CAT TL1055C, Genie GTH636, and CAT TL642C.
- Volume reductions were found to range from approximately 0-68% when compared to the 10,000-lb control telehandler, with the Genie GTH636 having the greatest volume reduction of the telehandlers capable of performing all ADR exercises.
- Weight reductions were found to range from approximately 35-70% when compared to the 10,000-lb control telehandler, with the Genie GTH636 having the largest calculated weight reduction of the telehandlers capable of performing all ADR exercises.

4.2 Recommendations

- Based on the field validation exercises, the following minimum equipment characteristics are recommended for the performance of all identified ADR tasks:
  - Minimum Power: 74 hp
  - Minimum Lift Capacity: 6,000 lb
  - Minimum Forward Reach: 24 ft
  - Minimum Lift Height: 36 ft
- The published load-capacity curve data were found to be relatively consistent with the field validated data and it is recommended that the published load-capacity curves be considered accurate for qualifying other equipment manufacturers and/or models for their ability to perform ADR tasks.
- It is recommended to evaluate the potential of integrating lifting capabilities with the simplified volumetric mixer. This could prove to be advantageous in the reallocation of equipment and/or manpower.

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14. ABSTRACT

Research was conducted at the U.S. Army Engineer Research and Development Center in Vicksburg, MS, to evaluate material handling equipment with a reduced logistical footprint for use by crater repair teams in airfield damage repair (ADR) scenarios. A market survey was conducted of available material handling equipment to populate a database of physical dimensions and load-capacity relationships according to identified ADR tasks. Selected equipment were identified and evaluated for maneuverability and efficiency in a realistic environment and compared to currently utilized material handling equipment. This report presents the results of the market survey and equipment evaluations. Results indicate that telehandlers with a minimum-rated capacity of 6,000 lb are capable of performing all identified ADR tasks with an efficiency at or better than the currently utilized 10,000-lb telehandler.

15. SUBJECT TERMS

	Crater repair	Material handling equipment
Airfield damage repair	Rapid-setting concrete	Extendable boom forklift
Expedient repair	Flowable fill	Telehandler

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